RSG INC.
ENVIRONMENT, ENERGY, & ACOUSTICS

Noise Modeling Study for Canton Wind Farm

Canton, Maine

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DATA ■ ANALYSIS ■ SOLUTIONS

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1. INTRODUCTION

Patriot Renewables is proposing to develop the Canton Mountain Wind project, a wind energy facility along the ridge of Canton Mountain in Canton, Maine.

The project is proposing to use either seven General Electric (GE) 2.75-103 2.75 MW wind turbines with 103-meter rotors and one GE 2.75-100 2.75 MW wind turbine with a 100 meter rotor, or eight Gamesa G90 2.0 MW turbines with 90 meter rotors. To support these turbines, Patriot Renewables is also proposing installation of an additional 34.5/115 kV transformer at the substation about 1.5 miles to the southwest of the project area.[1] This noise modeling report predicts the wind turbine and transformer sound levels in the area surrounding the project.

The report includes:

1) A description of the project site
2) A noise primer
3) A discussion of noise issues specific to wind turbines
4) A discussion of applicable noise limits
5) The results of computer propagation modeling
6) A summary and conclusions

2. PROJECT AREA

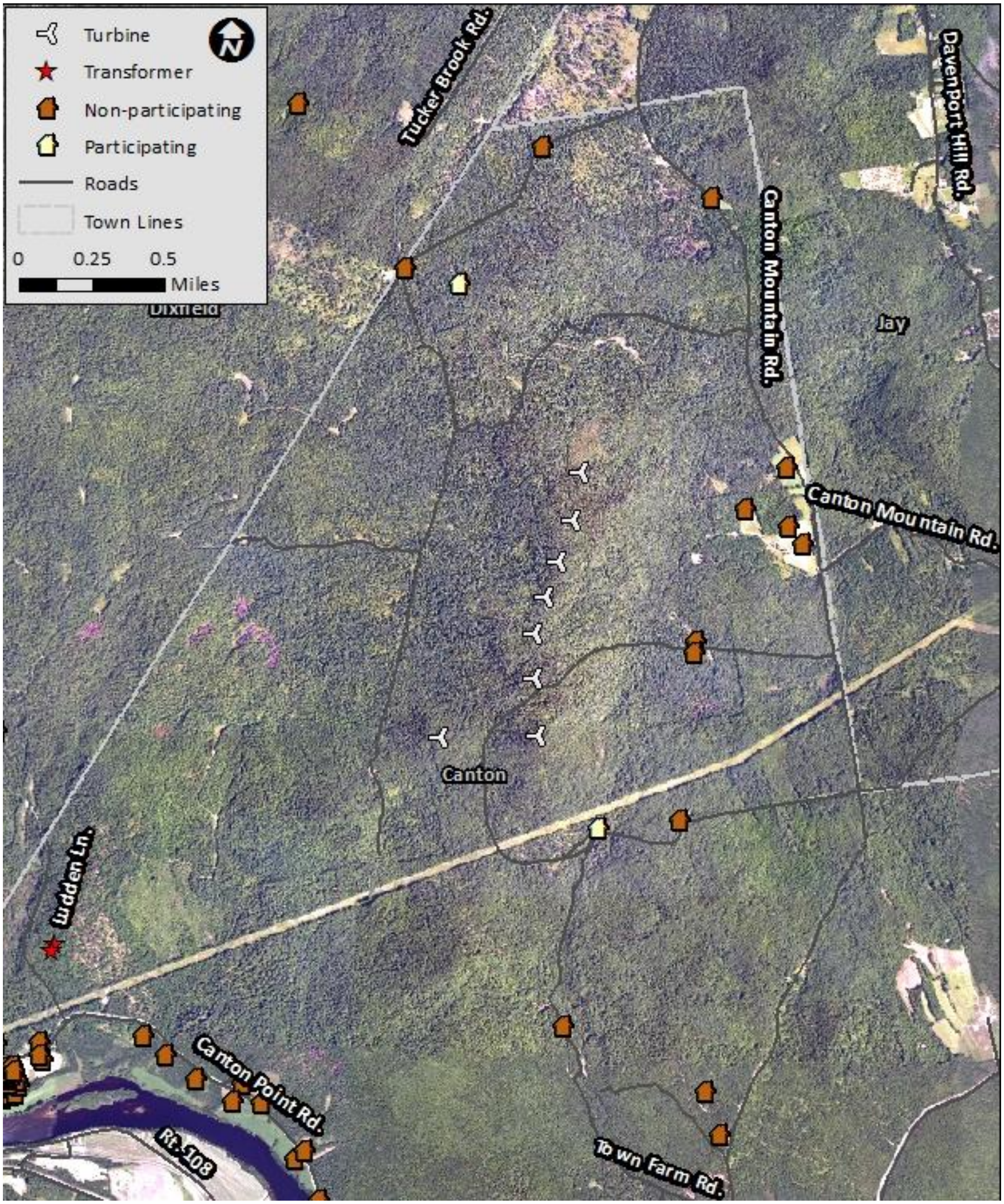
The proposed turbines would be located in the town of Canton in Oxford County, Maine (Figure 1). The area is mountainous and consists largely of forested areas. Canton Point Road runs 2,300 meters (7,550 feet) to the southwest of the project. Route 108 also runs to the southwest of the project, 2,800 meters (9,200 feet) distant and across the Androscoggin River. Davenport Hill Road runs 2,300 meters (7,550 feet) to the northeast of the project. The proposed turbines are located along the Canton Mountain ridgeline, which runs roughly north to south through the project area.

The distance between the turbines and the closest non-participating residence to the east is approximately 880 meters (2,900 feet). The closest non-participating residence to the southeast of the turbine array is approximately 930 meters (3,000 feet). The closest non-participating residence to the northwest is approximately 1,500 meters (4,900 feet).[2]

[1] This substation and one 34.5/115 kV transformer will be built for the Saddleback Ridge Wind project; however, they are modeled in this sound study in order to evaluate cumulative impacts.

[2] Distances are from the residence to the nearest turbine base.

Figure 1: Project Area



3. A NOISE PRIMER

3.1 What is Noise?

Noise is defined as "a sound of any kind, especially when loud, confused, indistinct, or disagreeable."[3] Passing vehicles, a noisy refrigerator, or an air conditioning system are sources of noise which may be bothersome or cause annoyance. These sounds are a part of generally accepted everyday life, and can be measured, modeled, and, if necessary, controlled.

3.2 How is Sound Described?

Sound is caused by variations in air pressure at a range of frequencies. Sound levels that are detectable by human hearing are defined in the decibel (dB) scale, with 0 dB being the approximate threshold of human hearing, and 135 dB causing pain and permanent damage to the ear. Figure 2 shows the sound levels of typical activities that generate noise.

The decibel scale can be weighted to mimic the human perception of certain frequencies. The most common of these weighting scales is the "A" weighting, and this scale is used most frequently in environmental noise analysis. Sound levels that are weighted by the "A" scale have units of dBA or dB(A).

To account for changes over time, a weighted average sound level called the "equivalent continuous" sound level (Leq) is often used. Leq averages sound pressure rather than decibels, and results in weighting the levels of loud and infrequent noises more heavily than quieter and more frequent noises. For example, a train passing by for one minute out of an hour could produce sound levels around 90 dBA while passing by, but the equivalent continuous sound level for the entire hour would be 72 dBA, if sound levels were 0 dBA for the rest of the hour. In comparison, the arithmetic decibel average for the hour would be 1.3 dB. This is due to the logarithmic relationship between sound pressure levels (in dB) and sound pressure fluctuations (in Pascals). Even though there is a 90 dB difference between 0 and 90 dBA, the sound pressure fluctuation at 90 dBA is 32,000 times greater than at 0 dBA. Consequently, averaging sound pressure fluctuations (as in an equivalent sound level) instead of the sound pressure level, weights loud infrequent sounds more heavily than continuous quieter sounds. The equivalent average sound level is often used in environmental noise analysis.

3.3 What is the Difference between Sound Pressure Levels and Sound Power Levels?

Both sound power and sound pressure levels are described in terms of decibels, but they are not the same thing. Sound power is a measure of the acoustic power emitted or radiated by a source. The sound power level of a source does not change with its surrounding conditions.

Sound pressure level is observed at a specific location and is related to the difference in air pressure above or below atmospheric pressure. This fluctuation in air pressure is a result of the sound power of a source, the

[3] "The American Heritage Dictionary of the English Language," Houghton Mifflin Company, 1981.

distance at which the sound pressure level is being observed, and the characteristics of the path and environment around the source and receiver. When one refers to sound level, they are generally speaking of the perceived level, or sound pressure level.

For example, a coffee grinder will have the same sound power whether or not it is grinding indoors or outdoors. The amount of sound the coffee grinder generates is always the same. However, if you are standing six feet away from the coffee grinder indoors, you would experience a higher sound pressure level than you would if you were six feet away from the coffee grinder outdoors in an open field. The reason for this is that the sound being emitted from the coffee grinder would bounce off walls and other surfaces indoors which would cause sound to build up and raise the sound pressure level.

Sound power cannot be directly measured. However, since sound pressure and sound power are related, sound power can be calculated by measurements of sound pressure and sound intensity. It can be helpful to note that over soft ground outside, the sound pressure level of a small source observed 50 feet away is roughly 33 dB lower than its sound power level.

3.4 How is Sound Modeled?

The decibel sound level is described on a logarithmic scale. One manifestation of this is that sound *power* increases by a factor of 10 for every 10 dB increase. However, for every 10 dB increase in sound pressure, we *perceive* an approximate doubling of loudness. Small changes in sound level, below 3 dB, are generally not perceptible.

For a point source, sound level diminishes or attenuates by 6 dB for every doubling of distance due to geometrical divergence. For example, if an idling truck is measured at 50 feet as 66 dBA, at 100 feet the level will decline to 60 dBA, and at 200 feet, 54 dBA, assuming no other influences. From a line source, like a gas pipeline or from closely spaced point sources, like a roadway or string of wind turbines, sound attenuates at approximately 3 dB per of doubling distance. These “line sources” transition to an attenuation of 6 dB per doubling at a distance of roughly a third of the length of the line source.

Other factors, such as intervening vegetation, terrain, walls, berms, buildings, and atmospheric absorption will also further reduce the sound level reaching the listener. In each of these, higher frequencies will attenuate faster than lower frequencies. Finally, the ground can also have an impact on sound levels. Harder ground generally increases and softer ground generally decreases the sound level at a receiver. Reflections off of buildings and walls can increase broadband sound levels by as much as 3 dB.

Table 1: Decibel Addition

If Two Sources Differ By	Add
0-1 dB	3 dB
2-4 dB	2 dB
5-9 dB	1 dB
>9 dB	0 dB

Figure 2: Basic Theory: Common Sounds in Decibels

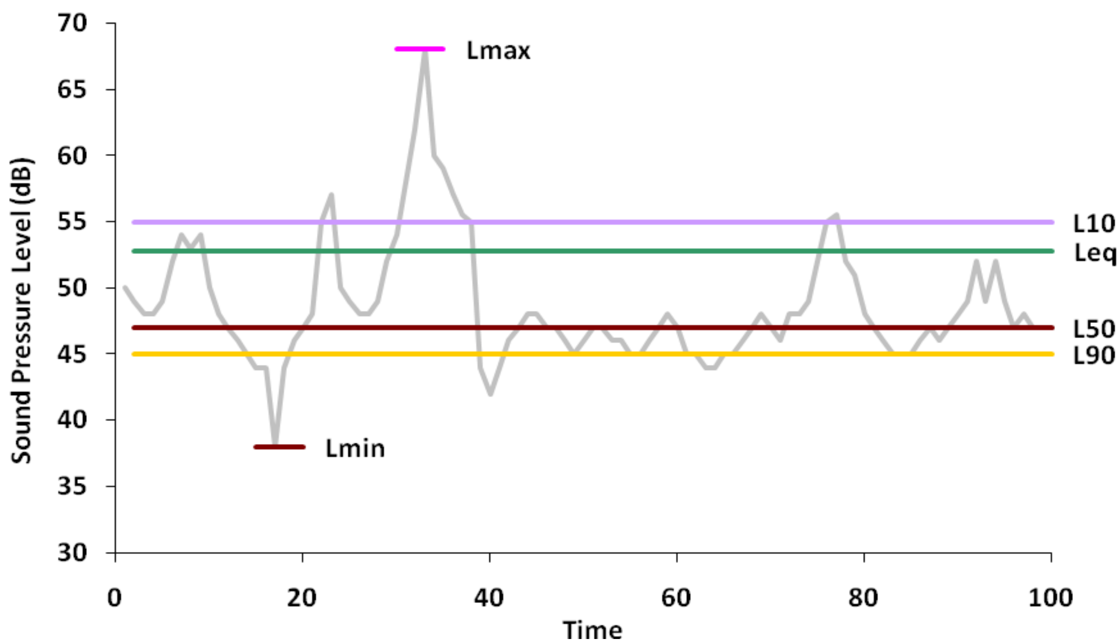
If we add two equal sources together, the resulting sound level will be 3 dB higher. For example, if one machine registers 76 dBA at 50 feet, two co-located machines would register 3 dB more, or 79 dBA at that distance. In a similar manner, at a distance of 50 feet, four machines, all operating at the same place and time, would register 82 dBA and eight machines would register 85 dBA. If the two sources differ in sound level then 0 to 3 dB will be added to the higher level as shown in Table 1.

3.5 Description of Terms

Sound can be measured in many different ways. Perhaps the simplest way is to take an instantaneous measurement, which gives the sound pressure level at an exact moment in time. The level reading could be 62 dB, but a second later it could 57 dB. Sound pressure levels are constantly changing. It is for this reason that it makes sense to describe noise and sound in terms of time.

The most common ways of describing noise over time is in terms of various levels. Take as an example, the sound levels measured over time shown in Figure 3. Instantaneous measurements are shown as a ragged grey line. The sound levels that occur over this time can be described verbally, but it is much easier to describe the recorded levels statistically. This is done using a variety of “levels” which are described below.

Figure 3: Example of Noise Measurement over Time and Descriptive Statistics



3.5.1 Equivalent Average Sound Level - Leq

One of the most common ways of describing noise levels is in terms of the continuous equivalent sound level (Leq). The Leq is the average of the sound pressure over an entire monitoring period and expressed as a decibel. The monitoring period could be for any amount of time. It could be one second ($Leq_{1\text{-sec}}$), one hour ($Leq_{(1)}$), or 24 hours ($Leq_{(24)}$). Because Leq describes the average pressure, loud and infrequent noises have a greater effect on the resulting level than quieter and more frequent noises. For example, in Figure 3, the median sound level is about 47 dBA, but the equivalent average sound level (Leq) is 53 dBA. Because it tends to weight the higher sound levels and is representative of sound that takes place over time, the Leq is the most commonly used descriptor in noise standards and regulations.

3.5.2 Percentile Sound Level - Ln

Ln is the sound level exceeded *n* percent of the time. This type of statistical sound level, also shown in Figure 3, gives us information about the distribution of sound levels over time. For example, the L10 is the sound level that is exceeded 10 percent of the time, while the L90 is the sound level exceeded 90% of the time. The L50 is exceeded half the time. The L90 is a residual base level which most of the sound exceeds, while the L10 is representative of the peaks and higher, but less frequent levels. When one is trying to measure a continuous sound, like a wind turbine, the L90 is often used to filter out other short-term environmental sounds that increase the level, such as dogs barking, vehicle passbys, wind gusts, and talking. That residual sound, or L90, is then the sound that is occurring in the absence of these noises.

3.5.3 Lmin and Lmax

Lmin and Lmax are simply the minimum and maximum sound level, respectively, monitored over a period of time.

4. NOISE STANDARDS

Canton Wind falls under the planning and zoning jurisdiction of the Maine Department of Environmental Protection (DEP), which has set out its regulations for noise in Control of Noise, Chapter 375.10. Generally speaking, commercial, industrial, and other non-residential areas are subject to hourly equivalent average $Leq_{(1)}$ sound level limits of 70 dBA in the daytime (7am to 7pm) and 60 dBA during the night (7pm to 7am).

The most restrictive DEP standards apply to quiet areas where pre-development hourly sound levels are 45 dBA or less during the day and 35 dBA or less during the night. Quiet areas are subject to hourly sound level limits of 55 dBA during the day (7am to 7pm) and 45 dBA during the night (7pm to 7am). Nighttime limits also apply to protected locations within 500 feet of an existing or proposed residence (or at the residence's property line, whichever is closer). In these areas, sound levels may not exceed 45 dBA. Beyond a distance of 500 feet or on properties without a residential structure, a daytime limit of 55 dBA applies.

This project will be evaluated against the daytime and nighttime quiet area criteria, whereby maximum sound levels may not exceed 55 dBA and 45 dBA, respectively.

The DEP standards apply various penalties to the overall sound levels which exceed certain tonal and short duration repetitive sound criteria. Given the nature of the turbines proposed for this location, these penalties are not expected to be applied.

5. SOUND LEVELS PRODUCED BY WIND TURBINES

5.1 Standards Used to Measure Wind Turbine Sound Emissions

A manufacturer of a wind turbine must test its turbines using two international standards:

1. International Electrotechnical Commission standard IEC 61400-11:2002(E), "Wind Turbine Generator Systems – Part 11: Acoustic Noise Measurement Techniques"
2. International Electrotechnical Commission standard IEC 61400-14:2005(E), "Wind Turbine Generator Systems – Part 14: Declaration of Apparent Sound Power Level and Tonality Values"

These standards provide sound power emission levels from a turbine, by wind speed and frequency. They also provide a confidence interval.

5.2 Manufacturer Sound Emissions Estimates

The project proposes to use either seven GE 2.75-103 2.75 MW and one GE 2.75-100 2.75 MW wind turbines with hub heights of 85 meters, or eight Gamesa G90 turbines with hub heights of 78 meters. To support these turbines, a 34.5/115 kV transformer will also be installed in a substation located to the southwest of the project. This transformer will join an existing 34.5/115 kV transformer that services the Saddleback Ridge Wind project, located about 1.5 miles southwest of the project. Sound emissions from both transformers were modeled to determine the cumulative impact.

Sound emissions from a wind turbine are measured as sound *power.* This is different from the sound *pressure* that one measures on a sound level meter. Sound *power* is the acoustical energy emitted by an object, and sound *pressure* is the measured change in pressure caused by acoustic waves at an observer location.

The sound *power* level is 105 ± 2 dBA from a GE 2.75-103 wind turbine, 106.5 ± 2 dBA from a GE 2.75-100, and 105 ± 2 dBA from a Gamesa G90, with wind speeds of 7 m/s and greater (10-meter anemometer height). The modeled levels in this report are 109 dBA, 110.5 dBA and 109 dBA respectively, as they include the manufacturer's uncertainty factor of 2 dB and a 2 dB factor to account for modeling uncertainty. The octave band sound power levels are shown in Table 2.

For the GE 2.75-103 and 2.75-100 turbines, no 1/3 octave band exceeds the Maine DEP definition of tonal noise (Figure 4 and Figure 5 respectively). The Gamesa G90 does have one tonal 1/3 octave band at 6.3 kHz (Figure 6). However, due to the high levels of atmospheric attenuation at higher frequencies, sound from the 6.3 kHz 1/3 octave band will attenuate to below the threshold of human hearing (0 dB) at even the worst case residence. Consequently, the 6.3 kHz tone produced by the Gamesa G90 will not exceed the tonal limits when measured at any residences.

Sound power for the modeled 34.5/115 kV transformer is taken from RSG's measurement of a similar transformer that is located at Vermont Electric Power Company, Inc.'s Vergennes substation.

Table 2: Spectral Sound Power Levels

Sound Source	Nominal Sound Power (dBA)	Octave Band Center Frequency								
		31.5 Hz	*63 Hz*	*125 Hz*	*250 Hz*	*500 Hz*	*1 kHz*	*2 kHz*	*4 kHz*	*8 kHz*
GE 2.75-103	105.0	78	92	96	97	96	99	98	90	74
GE 2.75-100	106.5	77	93	94	99	100	101	97	87	73
Gamesa G90	105.0	-	86	94	99	100	98	94	89	90
34.5/115 kV Transformer	93.0	35	52	90	81	86	86	75	68	55

Figure 4: Comparison of 1/3 Octave Band Sound Power for the GE 2.75-103 with Maine DEP Tonal Noise Definition

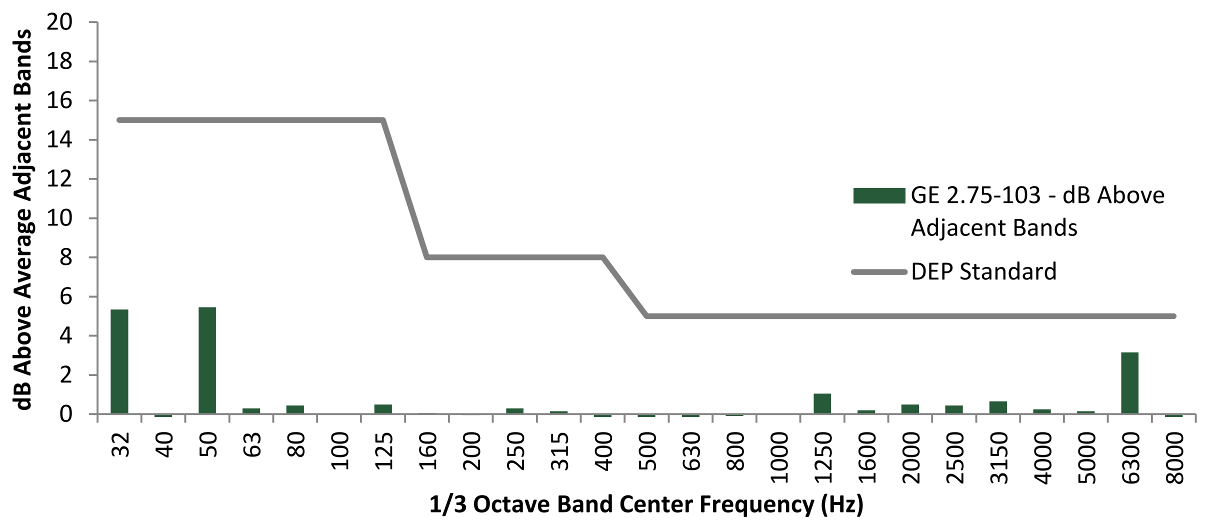


Figure 5: Comparison of 1/3 Octave Band Sound Power for the GE 2.75-100 with Maine DEP Tonal Noise Definition

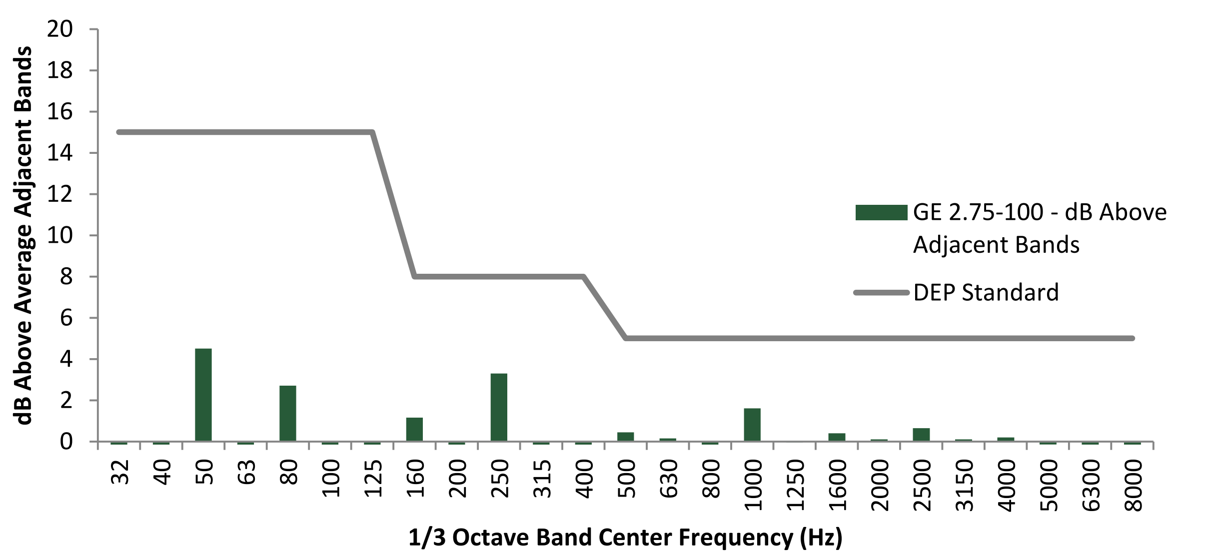
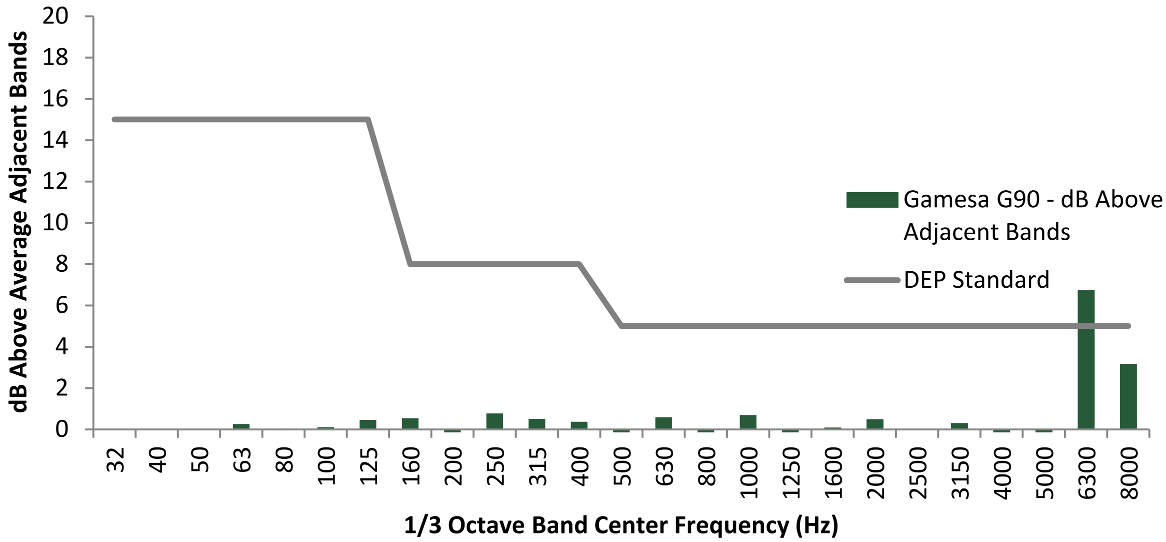


Figure 6: Comparison of 1/3 Octave Band Sound Power for the Gamesa G90 with Maine DEP Tonal Noise Definition



6. Sound From Wind Turbines – Special Issues

6.1 Wind Turbine Noise

Wind turbines generate two principle types of noise: aerodynamic noise, produced from the flow of air around the blades, and mechanical noise, produced from mechanical and electrical components within the nacelle.

Aerodynamic noise is the primary source of noise associated with wind turbines. These acoustic emissions can be either tonal or broadband. Tonal noise occurs at discrete frequencies, whereas broadband noise is distributed with little peaking across the frequency spectrum.

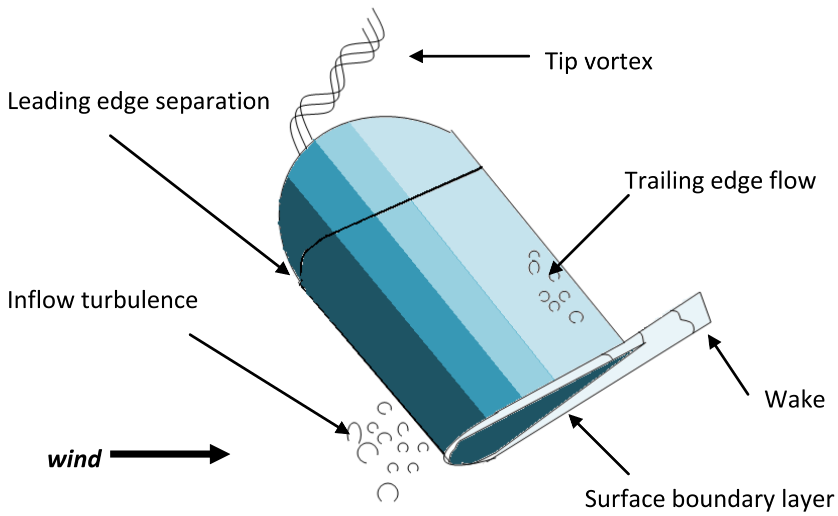
While unusual, tonal noise can also originate from unstable air flows over holes, slits, or blunt trailing edges on blades. Most modern wind turbines have upwind rotors designed to prevent blade impulsive noise. Therefore, the majority of audible aerodynamic noise from wind turbines is broadband at the middle frequencies, roughly between 200 Hz and 1,000 Hz.

Wind turbines emit aerodynamic broadband noise as the spinning blades interact with atmospheric turbulence and as air flows along their surfaces. This produces a characteristic "whooshing" sound through several mechanisms (Figure 7):

- *Inflow turbulence noise* occurs when the rotor blades encounter atmospheric turbulence as they pass through the air. Uneven pressure on a rotor blade causes variations in the local angle of attack, which affects the lift and drag forces to cause aerodynamic loading fluctuations. This generates noise that varies across a wide range of frequencies but is most significant at levels below 500 Hz.

- *Trailing edge noise* is produced as boundary-layer turbulence around the airfoil passes into the wake, or trailing edge, of the blade. This noise is distributed across a wide frequency range but is most notable at high frequencies between 700 Hz and 2 kHz.
- *Tip vortex noise* occurs when tip turbulence interacts with the surface of the blade tip. While this is audible near the turbine, it tends to be a small component of the overall noise further away.
- *Stall* or *separation noise* occurs due to the interaction of turbulence with the blade surface.

Figure 7: Airflow around a Rotor Blade

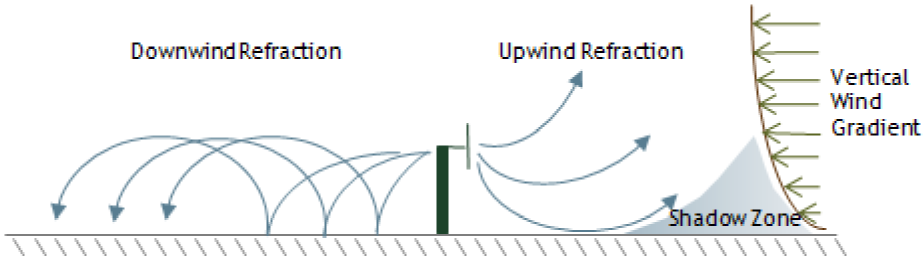


Mechanical noise from machinery inside the nacelle tends to be tonal in nature but can also have a broadband component. Potential sources of mechanical noise include the gearbox, generator, yaw drives, cooling fans, and auxiliary equipment. These components are housed within the nacelle, whose surfaces, if untreated, radiate the resulting noise. However modern wind turbines have nacelles that are designed to reduce internal noise, and rarely is the mechanical noise a significant portion of the total noise from a wind turbine.

6.2 Meteorology

Meteorological conditions can significantly affect sound propagation. The two most important conditions to consider are wind shear and temperature lapse. Wind shear is the difference in wind speeds by elevation and temperature lapse rate is the temperature gradient by elevation. In conditions with high wind shear (large wind speed gradient), sound levels upwind from the source tend to decrease and sound levels downwind tend to increase due to the refraction, or bending, of the sound (Figure 8).

Figure 8: Schematic of the Refraction of Sound Due to Vertical Wind Gradient (Wind Shear)



With temperature lapse, when ground surface temperatures are higher than those aloft, sound will tend to refract upwards, leading to lower sound levels near the ground. The opposite is true when ground temperatures are lower than those aloft (an inversion condition).

The term “Stability Class” is used to describe how stable the atmosphere is. Unstable atmospheres can be caused by high winds and/or high solar radiation. This creates turbulence and tends to break up and dissipate sound energy. Highly stable atmospheres, which tend to occur on clear nights with low ground-level wind speeds, tend to minimize atmospheric turbulence and are generally more favorable to down-wind propagation.

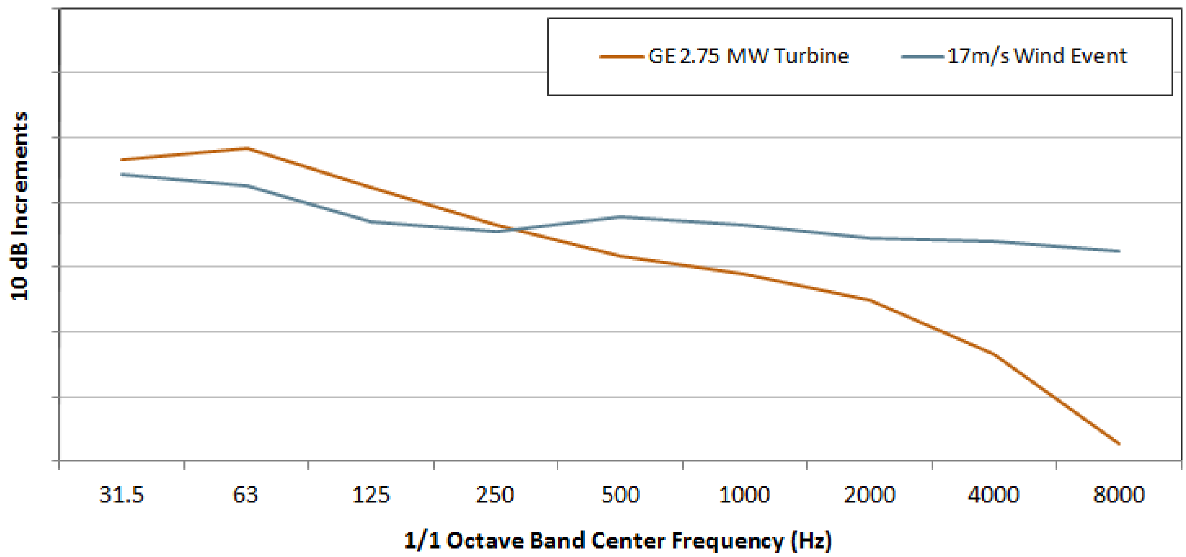
In general terms, sound propagates best under stable conditions with a strong temperature inversion. This occurs during the night and is characterized by low ground level winds.[4] Wind speeds under very stable conditions (Stability Class G) can be too low to generate electricity, therefore the turbines are not spinning, unless this inversion happens during a time with high wind shear. As a result, worst-case conditions for wind turbines tend to occur under moderate nighttime temperature inversions. Therefore, this is the default condition for modeling wind turbine sound.

6.3 Masking

As mentioned above, sound levels from wind turbines are a function of wind speed. Background sound is also a function of wind speed, i.e., the stronger the winds, the louder the resulting background sound. This effect is amplified in areas covered by trees and other vegetation. The sound from a wind turbine can often be masked by wind noise at downwind receivers because the frequency spectrum from wind is very similar to the frequency spectrum from a wind turbine. Figure 9 compares the sound spectrum measured during a 17 m/s wind event to a GE 2.75-103 wind turbine. As shown, the shapes of the spectra are very similar at the lower frequencies. At higher frequencies, the sounds from the masking wind noise are higher than the wind turbine. As a result, the masking of turbine noise is possible at higher wind speeds.

[4]The amount of propagation is highly dependent on surface conditions and the frequency of the sound. Under some circumstances highly stable conditions can show lower sound levels.

Figure 9: Comparison of Frequency Spectra from Wind and a GE 2.75-103 Wind Turbine



It is important to note that while winds may be blowing at turbine height, there may be little to no wind at ground level. This is especially true during strong wind gradients (high wind shear), which mostly occur at night. This can also occur on the leeward side of ridges where the ridge blocks the wind.

We would expect some masking of wind turbine sound, especially with residences on the eastern side of the project at higher wind speeds.

6.4 Infrasound and Low Frequency Sound

Low frequency aerodynamic tonal noise is typically associated with downwind rotors on horizontal axis wind turbines. In this configuration, the rotor plane is behind the tower relative to the oncoming wind. As the turbine blades rotate, each blade crosses behind the tower's aerodynamic wake and experiences brief load fluctuations. This causes short, low-frequency pulses or thumping sounds called *blade impulsive noise*. Large modern wind turbines are "upwind", where the rotor plane is upwind of the tower. As a result, this type of low frequency noise does not occur in all but the most swirling winds.

Infrasound is sound pressure fluctuations at frequencies below about 20 Hz. Sound below this frequency is generally not audible. Low frequency sound is in the audible range of human hearing, that is, above 20 Hz, but below 100 to 200 Hz depending on the definition.

At very high sound levels (greater than 110 dB), infrasound can cause health effects such as decreased alertness and sleepiness.[5] Infrasound can also rattle light-weight building partitions. However, modern wind turbines, with the hub upwind of the tower, do not create this level of infrasound. As a result, infrasound analysis is not necessary.

[5] Edge, Phillip and Mayes, William. "Description of Langley Low-Frequency Noise Facility and Study of Human Response to Noise Frequencies Below 50 CPS," National Aeronautics and Space Administration, January 1966.

Low frequency sound is a component of the sound generated by wind turbines. It is absorbed less by the atmosphere and ground than higher frequency sound. As with infrasound, high levels of low frequency sound can induce rattling in light-weight partitions in buildings. The American National Standards Institute standard, ANSI S12.2, "Criteria for Evaluating Room Noise", recommends that levels be kept below 65 dB at 16 Hz, 65 dB at 31.5 Hz, and 70 dB at 70 Hz inside the building to prevent moderately perceptible vibration and rattles.

Low frequency sound is primarily generated by the generator and mechanical components. Much of the mechanical noise has been reduced in modern wind turbines through improved sound insulation at the hub. Low frequency sound can also be generated by the blades at higher wind speeds when the inflow air is very turbulent. However, at these wind speeds, low frequency sound from the wind turbine blades is often masked by wind noise at the downwind receivers.

Finally, low frequency sound is absorbed less by the atmosphere and ground than higher frequency sound. Our modeling took into account downward diffraction under a moderate nighttime temperature inversion and differing atmospheric absorption between low and high frequency sound.

7. SOUND MODELING

7.1 Modeling Software

Modeling was completed for the project using Cadna A acoustical modeling software. Created by Datakustik GmbH, Cadna A is an internationally accepted acoustical model, used by many other noise control professionals in the United States and abroad. The software has a high level of reliability and follows methods specified by the International Standards Organization in their ISO 9613-2 standard, "Acoustics – Attenuation of sound during propagation outdoors, Part 2: General Method of Calculation." The ISO standard states,

> This part of ISO 9613 specifies an engineering method for calculating the attenuation of sound during propagation outdoors in order to predict the levels of environmental noise at a distance from a variety of sources. The method predicts the equivalent continuous A-weighted sound pressure level … under meteorological conditions favorable to propagation from sources of known sound emissions. These conditions are for downwind propagation … or, equivalently, propagation under a well-developed moderate ground-based temperature inversion, such as commonly occurs at night.

The model takes into account source sound power levels, surface reflection and absorption, atmospheric absorption, geometric divergence, meteorological conditions, walls, barriers, berms, and terrain.

Standard modeling methodology takes into account moderate nighttime inversions and moderate wind speeds, there may be meteorological conditions that result in higher levels of sound from the turbines. In particular, much higher wind speeds can account for greater downwind propagation. Adjustments can be made to take into account the more extreme conditions. For this study, we modeled the sound propagation in accordance with ISO 9613-2 for omnidirectional wind, using spectral ground attenuation and a ground absorption factor of 0.5 (to represent mixed ground). As shown in Table 2, a 2 dB manufacturer's confidence interval was added to the sound power level of the wind turbines. In addition, a modeling uncertainty margin of 2 dB was also added to the sound power level of the wind turbines.

A 15-meter by 15-meter grid of receivers was set up in the model covering 32 square miles around the site. This accounts for a total of about 373,000 modeled receivers. A receiver is a point above the ground at which the computer model calculates a sound level. Separate discrete receivers were added to the model in addition to the grid to represent 60 residences within 1 mile of the proposed wind turbines, with an additional 2 receivers representing the worst case locations within a 500 foot radius of homes near the project. Grid receivers were modeled at a height of 1.5 meters, discrete receivers representing homes were modeled at a height of 4.0 meters, and discrete receivers representing other locations were modeled at a height of 1.5 meters.

Two different turbine model configurations are proposed for this project. The first configuration includes seven GE 2.75 MW turbines with 103 meter diameter rotors and one GE 2.75 MW turbine with a 100 meter diameter rotor. The other configuration is composed of eight Gamesa G90 2.0 MW turbines with 90 meter diameter rotors. In addition to the wind turbines, two 34.5/115 kV transformers were modeled. One transformer will support the proposed Canton Mountain Wind project and the other will support the already-permitted Saddleback Ridge Wind project.

8. SOUND PROPAGATION MODELING RESULTS

8.1 Overall Results

Modeling results at full sound power for the turbine configuration that includes GE turbines is shown in Figure 10, and the configuration with Gamesa turbines is shown in Figure 11. In the GE configuration, the highest hourly Leq at a residence is 44.8 dBA and the highest sound level 500 feet from a residence is 45.6 dBA. In the Gamesa configuration, the highest sound level at a residence is 45.2 dBA and the highest sound level 500 feet from a residence is 45.2 dBA.[6]

8.2 Mitigation Recommendations

To decrease sound levels to below Maine DEP specified levels, Noise Reduced Operations (NRO) can be applied to turbines. In the GE turbine configuration, NRO level 1 (1 dB sound power reduction) was applied to turbines T3, T4, T5, and T6. In this configuration, the highest sound level at a residence is 44.2 dBA and the highest sound level 500 feet from a residence is 45.0 dBA. Results are shown in Figure 12. In the Gamesa configuration NRO level 1 (1.8 dB sound power reduction) was applied to turbine T4. In this configuration the highest sound level at a residence is 45.0 dBA and the highest sound level 500 feet from a residence is 45 dBA. Results are shown in Figure 13.

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[6] A slight outcropping between the wind farm and residence 4, causes the buffer location to be slightly shielded from the turbines. Due to the lower hub height of the Gamesa turbines, this shielding is more pronounced than with the GE turbines, allowing the sound level at the 500 foot buffer to equal to the sound level at the residence. In comparison, sound levels are higher at the 500 foot buffer than at the residence with the GE turbines, as would normally be expected.

8.3 Low Frequency Sound

A criterion for noise induced building vibration at the exterior of buildings can be found in ANSI S12.2-2008, "Criteria for evaluating room noise." The criteria for "moderately perceptible vibration and rattle likely" are 65 dB at 16 and 31.5 Hz, and 70 dB at 63 Hz. In the GE configuration, the sound level at the worst case residence is 62 dB in both the 31.5 Hz and 63 Hz 1/1 octave bands.[7] No data is available in the 31.5 Hz 1/1 octave band for the Gamesa G90, but the sound level in the 63 Hz 1/1 octave band is 53 dB at the worst case residence.

9. Short-Duration Repetitive Sounds

There are currently no ANSI, IEC, or other standards used to predict short-duration-repetitive-sounds (SDRS) from wind turbines. The cause of SDRS is debated, but it is likely a function of the different wind speeds at the top and bottom of the rotor (wind shear) and turbulence (Bowdler 2008, Dunbabin 1996, Oerlemans and Mendez, 2005, van den Berg 2005). The turbulence can be naturally occurring or created by wakes from upwind turbines.

Several papers have studied the theoretical effect of wind shear on the "swishing" sound from wind turbines (Lee, et al. 2009, Oerlemans and Schepers, 2009). They found that much of this amplitude modulation can be explained simply by the difference in broadband blade noise created by higher wind speeds at the top versus the bottom of the rotor rotation. Higher wind shear would result in higher amplitude modulation. This amplitude modulation is broadband and not infrasonic.

Terrain breaks up the tendency to create stable wind layers. As a result, in turbine locations such as those found along Canton Mountain, there tend to be fewer instances of excessive wind shear

To evaluate whether this area is subject to very high wind shear, we reviewed a year of data from the Canton Mountain meteorological tower. The grey boxes in Figure 14 represents 90% of the 10-minute with hub-height wind speeds of 3 m/s or greater. Instances of high wind shear ($\alpha > 0.55$) occur 8% of the time for all hours.

Excessive turbulence can increase the level of sound from a wind turbine and it may also contribute to SDRS. Turbulence may be naturally occurring, caused by thermal mixing and ground roughness, for example. Or, it can be caused by the wake from upwind turbines. To evaluate naturally occurring turbulence, we reviewed one year of meteorological data and plotted turbulence intensity for 60,815 10-minute data points. As shown on Figure 15, higher turbulence occurs during the day, due to higher solar radiation. Overall, 89% of the data points are below 0.20 turbulence intensity, with most of those periods above this figure occurring during the day.[8]

Turbulence intensity is highest at the lowest wind speeds, when sound output from the wind turbines is lower. Figure 16 shows seasonal turbulence intensity from the Canton Mountain met tower plotted against wind speed.

[7] Note that these sound levels are unweighted. A brief primer on weightings is found in Section 3.2.

[8] Most wind turbines are tested in turbulence intensity environments below 0.2.

Figure 10: Sound Propagation Modeling Results with 7 GE 2.75-103 and 1 GE 2.75-100 Turbines

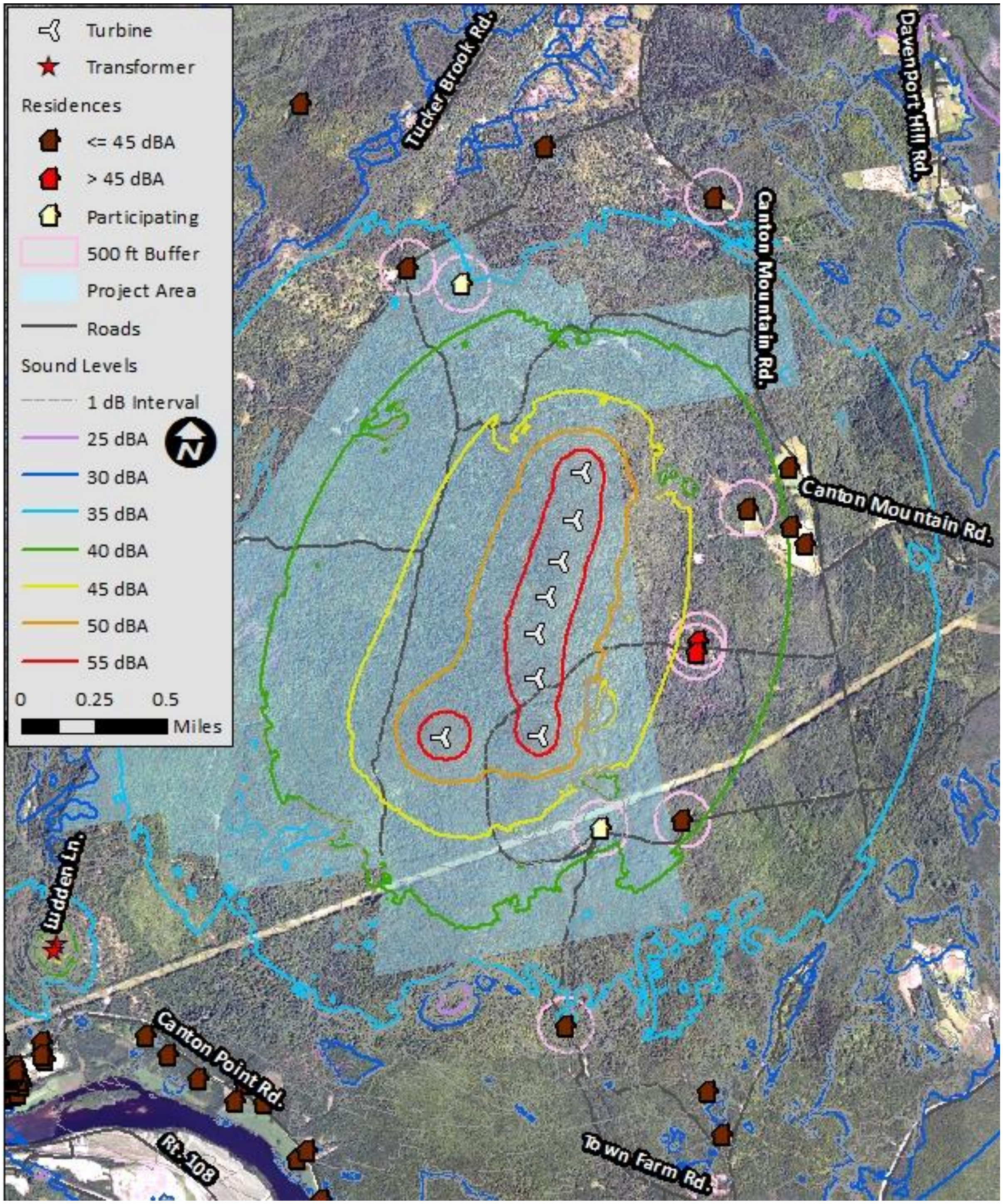


Figure 11: Sound Propagation Modeling Results with Gamesa G90 Turbines

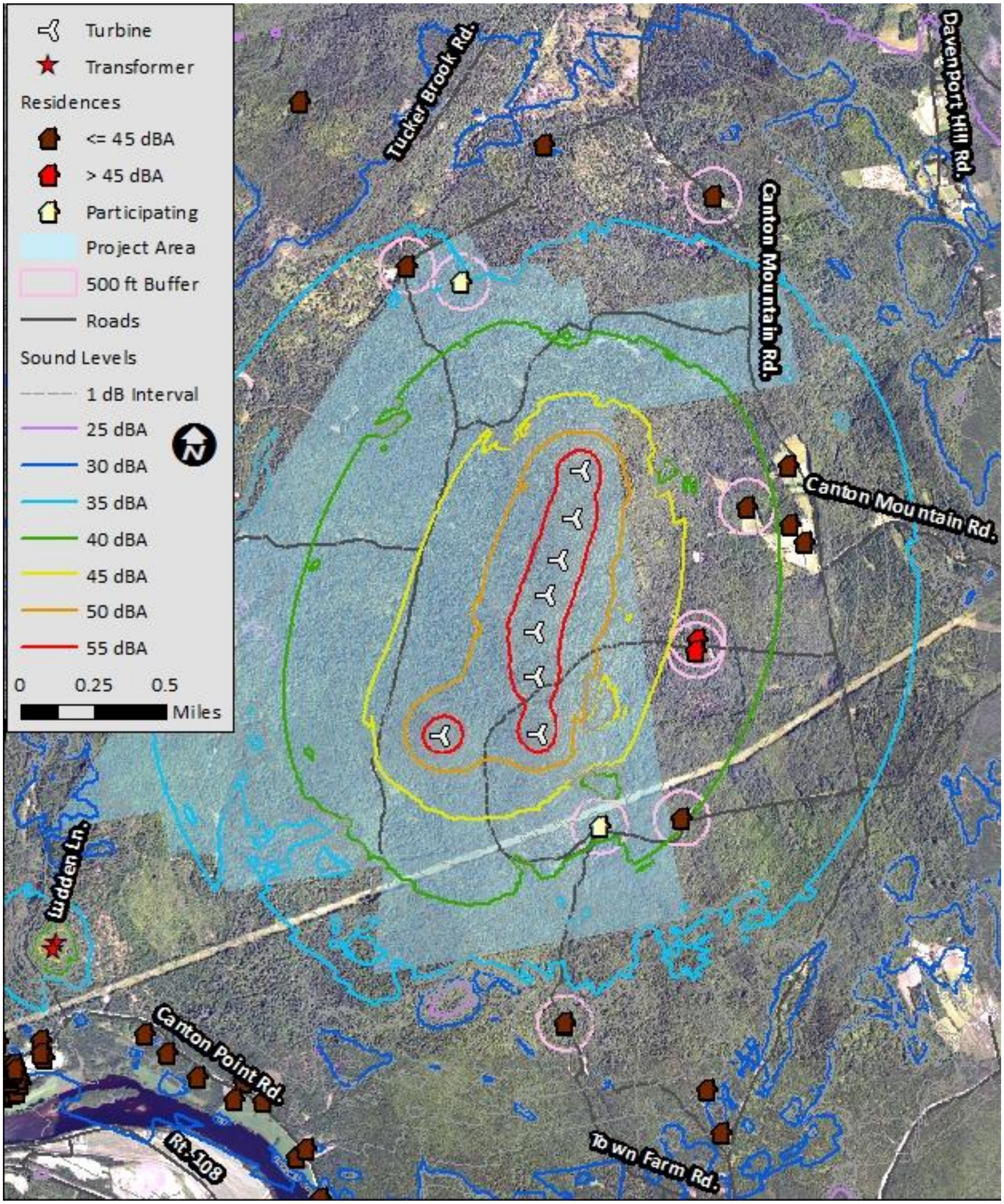


Figure 12: Mitigated Sound Propagation Modeling Results with 7 GE 2.75-103 and 1 GE 2.75-100 Turbines

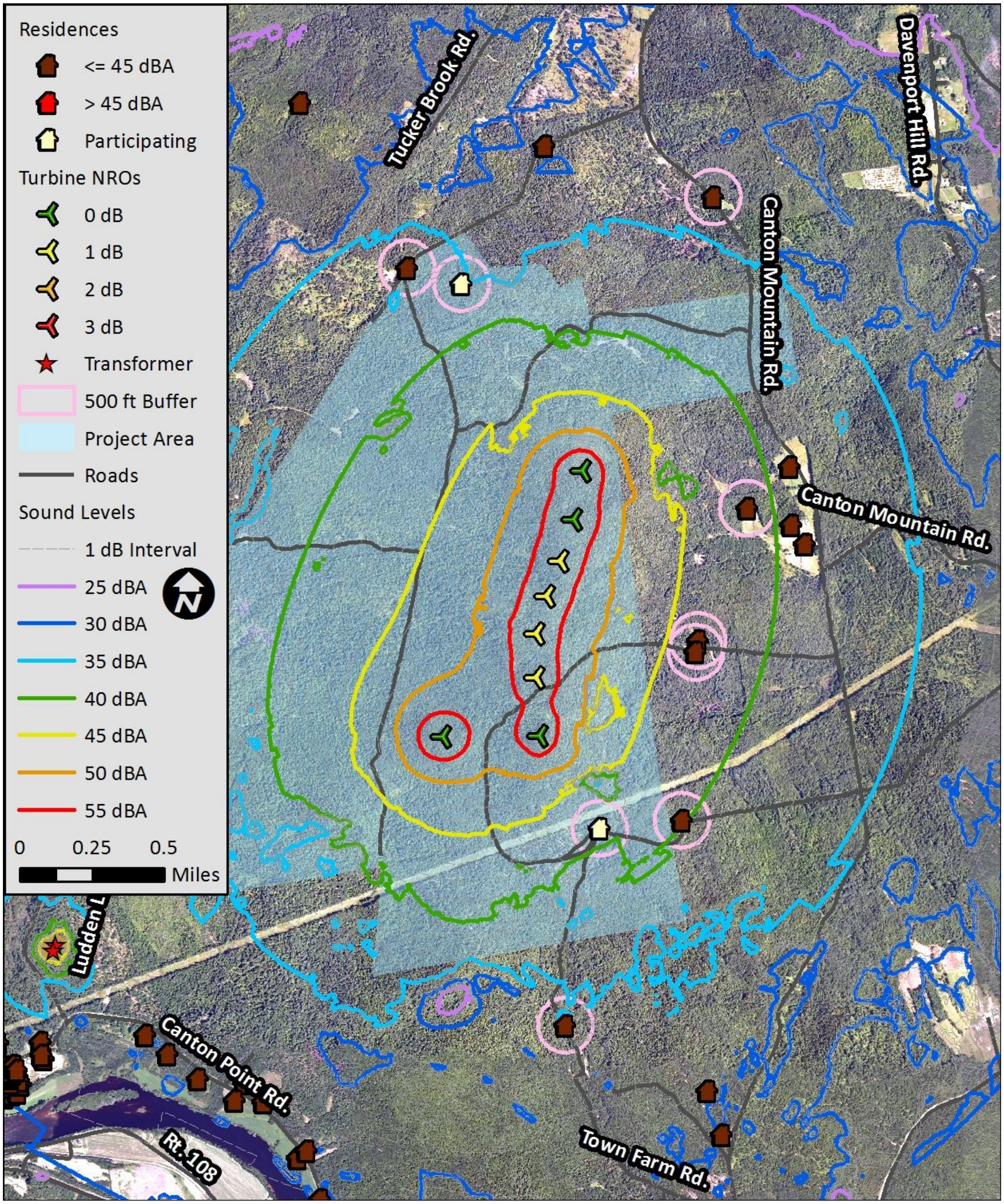


Figure 13: Mitigated Sound Propagation Modeling Results with Gamesa G90 Turbines

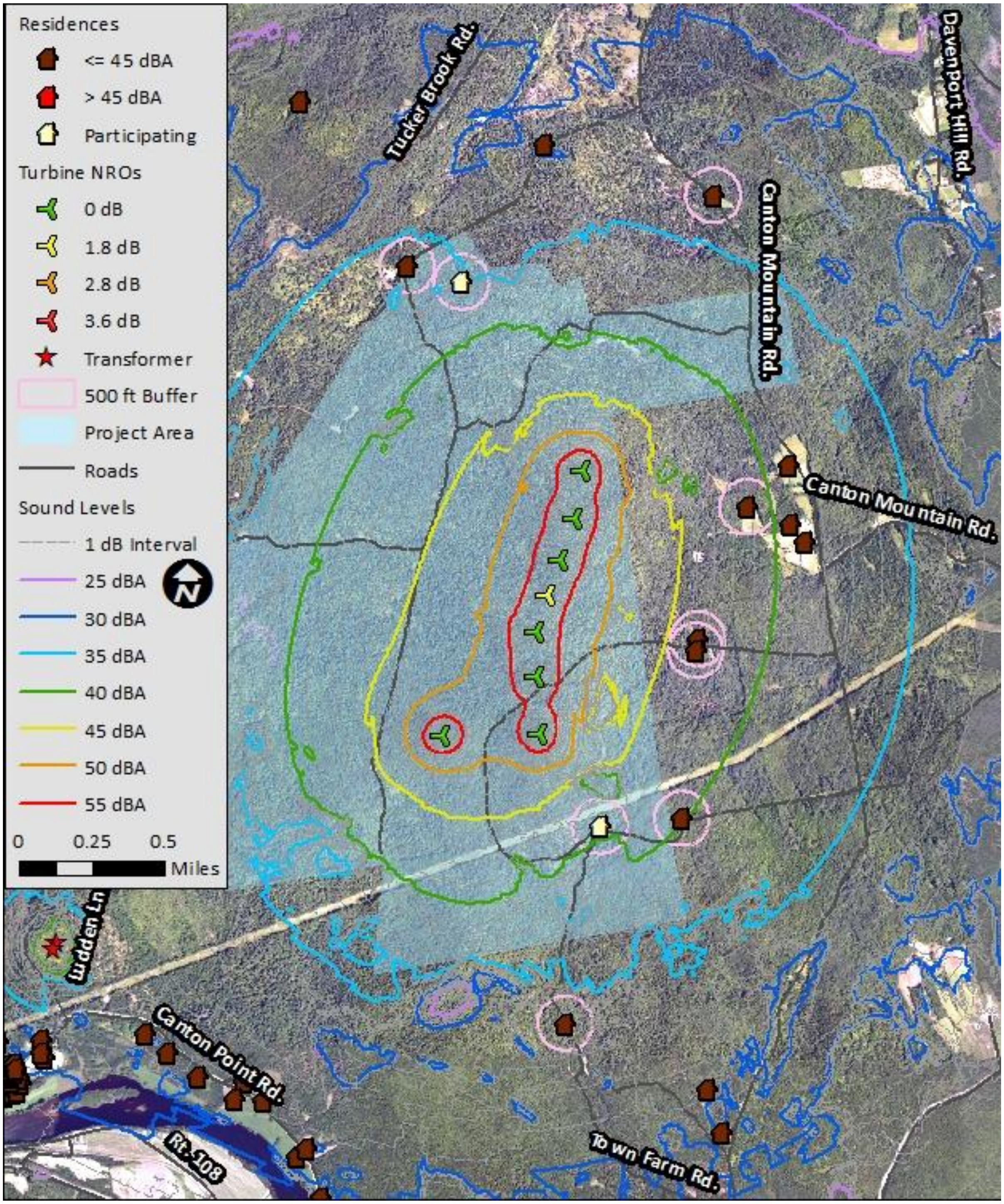


Figure 14: Wind profile power law exponent by time of day for 85 meter predicted wind speeds above 4 m/s. Boxes show 90% of data and "whiskers" are the +5% and -5% outliers

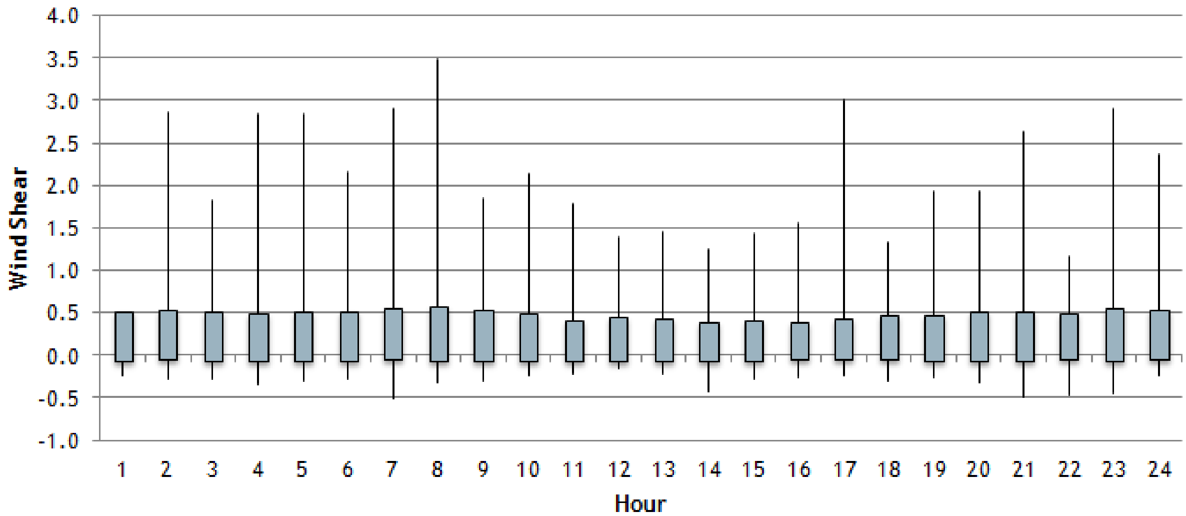


Figure 15: Turbulence intensity by wind speed. Boxes show 90% of data and "whiskers" are the +5% and -5% outliers

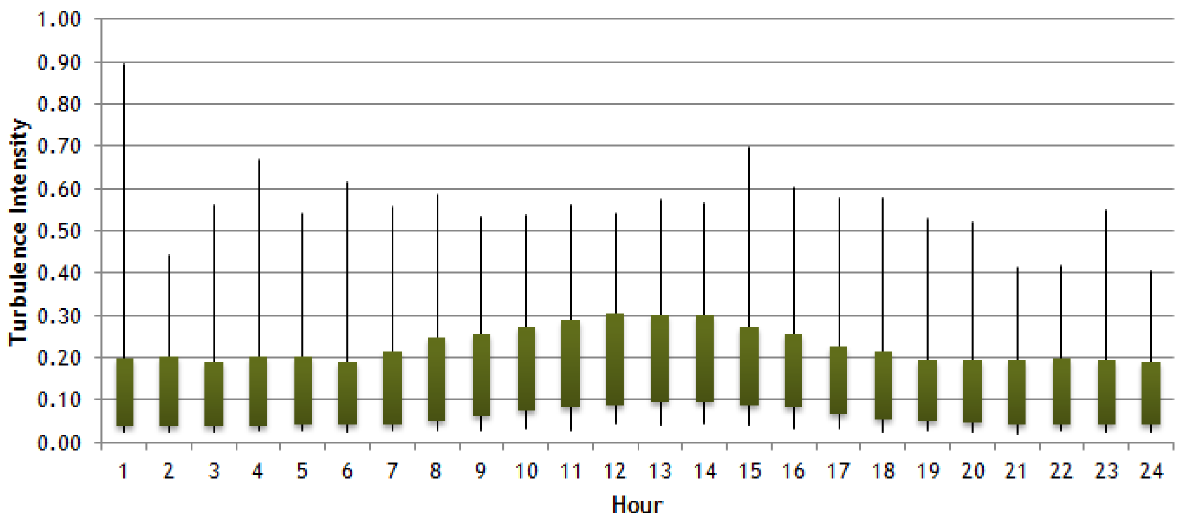
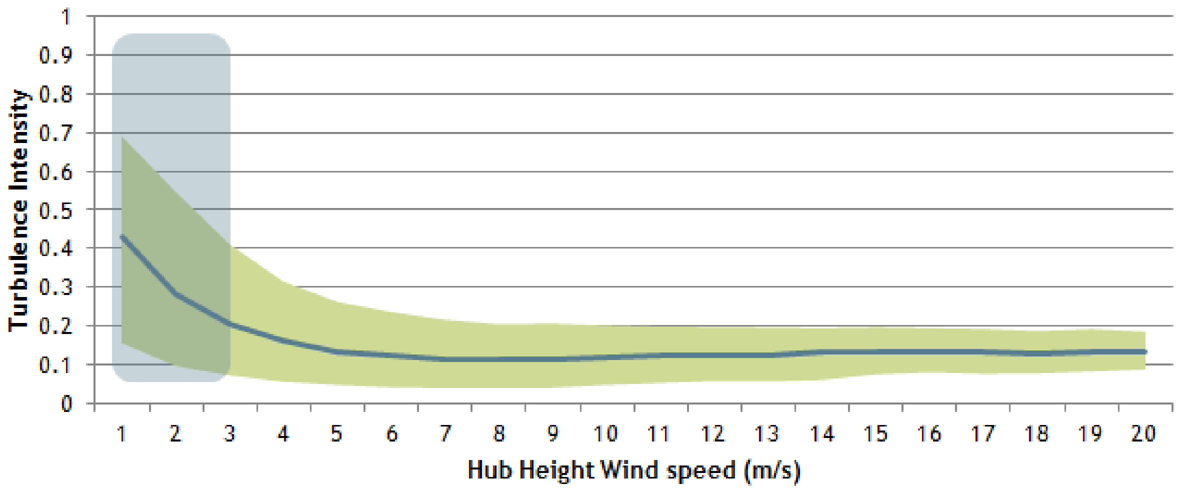


Figure 16: Turbulence Intensity by Wind Speed.

Green area bounds the 5th percentile and 95th percentile turbulence intensities by hub height wind speed. Shaded area shows wind speeds too low for turbine operation. Blue line shows the average.



While it is not possible, at this time, to calculate the extent of SDRS at Canton, the analysis shown above indicates that the site characteristics are not conducive to common occurences of SDRS.

Inflow turbulence between turbines in a turbine string can also affect noise from the wind farm. Proper turbine siting and operation minimizes this type of turbine wake impact.

If post-construction monitoring is required, data will be collected to evaluate whether SDRS is occuring.

10. Construction Impacts

The construction of the turbines will take place primarily on the ridge line. While there may be activity closer to residences for road construction and utility work, such work will be of a relatively short duration.

The equipment used for the construction will be varied. Some of the louder pieces of equipment are shown in Table 4 along with the approximate maximum sound pressure levels at 50 feet (15.2 m) and 2,100 feet (640 m). Sound levels at this distance are likely to be lower due to the presence of dense vegetation between the construction areas and the nearest residences.

Blasting may be required. However, the amount of blasting will be limited. Blasts will be warned as per federal requirements. Blasts will be designed by a licensed blasting company and charges and delays will be set such that Bureau of Mines standards for vibration and airblast will be complied with.

Major construction work, such as clearing for the access roads, will occur primarily during the day, however, minor construction work may extend earlier or later.

Due to the setbacks involved and the limited duration of the activities, construction noise should not pose undue quality of life concerns.

Table 3: Maximum Sound Levels From Various Construction Equipment

Equipment	Sound Pressure Level at 50 feet (dBA)	Sound Pressure Level at 2,100 feet (dBA)[9]
M-250 Liftcrane	82.5	44
2250 S3 Liftcrane	78	40
Excavator	83	47
Dump truck being loaded	86	51
Dump truck at 25 mph accelerating	76	38
Tractor trailer at 25 mph accelerating	80	44
Concrete truck	81	43
Bulldozer	85	47
Rock drill	100	57
Loader	80	39
Backhoe	80	42
Chipper	96	61

11. CONCLUSIONS

Patriot Renewables proposes to construct and operate either seven GE 2.75-103 2.75 MW and one GE 2.75-100 2.75 MW turbines, or eight Gamesa G90 2.0 MW wind turbines along the Canton Mountain ridgeline. These turbines have a nominal sound power rating of 105 dBA in the case of the GE 2.75-103 and Gamesa G90, and 106.5 dBA for the GE 2.75-100. A 34.5/115 kV transformer will be installed at the substation about 1.5 miles southwest of the project, which has been included in the model; however, the transformer does not significantly affect protected locations.

This report evaluated the potential noise impacts of the project and concluded the following:

1) A 45 dBA nighttime (7 pm-7 am) noise limit and a 55 dBA daytime (7 am to 7 pm) noise limit apply to the project, according to Maine DEP Chapter 375.10 regulations.
2) The proposed GE 2.75-103 and GE 2.75-100 wind turbines do not generate any tonal sound according the Maine DEP standard. The proposed Gamesa G90 does produce a 6.3 kHz tone, but due to atmospheric attenuation, there will be no tonal noise at protected locations.
3) Sound propagation modeling was conducted using conservative assumptions, including a ground absorption factor of 0.5 (to represent mixed ground), a 2 dB uncertainty factor on top of the manufacturer's warranteed maximum sound power levels, and an additional 2 dB factor to account for modeling uncertainty.
4) At maximum sound power levels, the highest modeled sound level at and within 500 feet of a non-participating residence was 44.8 and 45.6 dBA, respectively (Receivers 4 and 4B) for the GE configuration.

[9] Assumes hard ground around construction site, and ISO 9614-2 propagation with no vegetation reduction. Actual sound levels will likely be lower given the prevalence of dense vegetation and soft ground around the site.

5) At maximum sound power levels, the highest modeled sound level at and within 500 feet of a non-participating residence was 45.2 and 45.2 dBA, respectively (Receivers 4 and 4B) for the Gamesa configuration.
6) For nighttime compliance, Noise Reduced Operations on GE turbines T3, T4, T5, and T6 reduces sound levels to 45.0 dBA at the 500 foot buffer around the protected location with the highest predicted noise impacts from the project (Receiver 4B).
7) For nighttime compliance, Noise Reduced Operations on Gamesa turbine T4 reduces sound levels to 45.0 dBA at the 500 foot buffer around the protected location with the highest predicted noise impacts from the project (Receiver 4B).
8) The modeled levels of low frequency sound will not create perceptible building vibration.

The modeled results described in this report indicate the Canton Mountain Wind project, with imposition of nighttime Noise Reduced Operations on selected wind turbines, meets the noise standards set out by the Maine Department of Environmental Protection, Chapter 375(10) noise rules.

APPENDIX A: RECEIVER LOCATIONS AND RESULTS

Figure A1: Residence and Buffer Locations

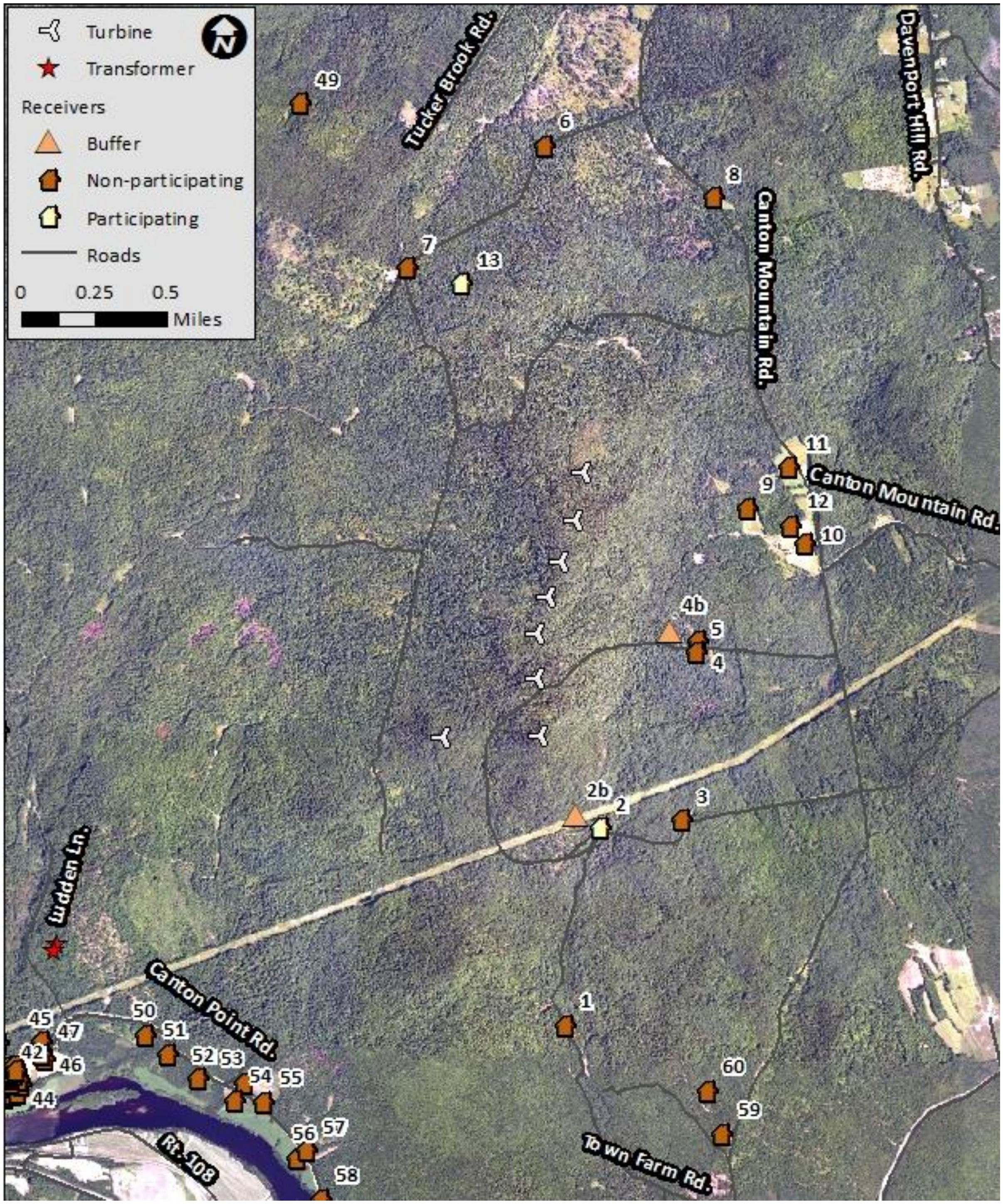


Table A1: Discrete Receiver Results for both Unmitigated and Mitigated Turbine Layouts

Receiver ID	Status	Sound Pressure Levels (dBA)				Relative Height (m)	Coordinates (UTM NAD 83 Z19N)			Distance to Nearest Turbine (m)	Distance to Nearest Turbine (ft)
		Gamesa G90		GE 2.75 103 and 100							
		Unmit	Mit	Unmit	Mit		X (m)	Y (m)	Z (m)		
1	Non-participating	36	36	36	36	4	396535	4927470	192	1645	5396
2	Participating	42	42	42	41	4	396726	4928565	290	648	2127
3	Non-participating	42	42	42	41	4	397183	4928611	279	950	3117
4	Non-participating	45	45	45	44	4	397273	4929612	271	906	2971
5	Non-participating	45	45	45	44	4	397261	4929546	270	914	3000
6	Non-participating	32	32	32	32	4	396419	4932369	280	1833	6014
7	Non-participating	38	38	38	38	4	395653	4931689	350	1496	4909
8	Non-participating	35	35	35	35	4	397358	4932082	279	1702	5585
9	Non-participating	43	43	43	42	4	397547	4930349	241	970	3183
10	Non-participating	41	41	40	40	4	397867	4930150	226	1321	4333
11	Non-participating	41	41	40	40	4	397782	4930579	238	1178	3866
12	Non-participating	41	41	41	40	4	397793	4930254	230	1228	4028
13	Participating	38	38	38	37	4	395957	4931599	364	1242	4076
14	Non-participating	21	21	22	22	4	392501	4926924	146	3984	13069
16	Non-participating	29	29	30	29	4	392817	4927103	143	3623	11885
17	Non-participating	28	28	29	28	4	392918	4927107	141	3536	11602
18	Non-participating	30	30	31	31	4	393117	4927231	143	3302	10834
19	Non-participating	31	30	31	31	4	393238	4927258	139	3188	10460
20	Non-participating	29	29	29	29	4	393311	4927258	139	3129	10266
21	Non-participating	33	33	33	33	4	393377	4927368	144	3012	9881
22	Non-participating	32	32	32	32	4	393379	4927211	140	3102	10178
23	Non-participating	31	31	32	31	4	393338	4927199	139	3142	10307
24	Non-participating	32	32	32	32	4	393343	4927181	139	3149	10332
25	Non-participating	32	32	32	32	4	393381	4927185	139	3117	10225
26	Non-participating	32	31	32	32	4	393350	4927160	139	3157	10356
27	Non-participating	32	32	32	32	4	393397	4927143	139	3130	10268
28	Non-participating	31	31	32	32	4	393352	4927132	139	3172	10407
29	Non-participating	31	31	32	32	4	393418	4927105	137	3137	10293
30	Non-participating	31	31	31	31	4	393357	4927069	136	3207	10522
31	Non-participating	31	31	32	32	4	393414	4927068	135	3164	10379
32	Non-participating	30	30	31	31	4	393366	4927048	134	3214	10544
33	Non-participating	31	31	32	32	4	393455	4927087	135	3120	10237
34	Non-participating	32	32	32	32	4	393449	4927126	137	3100	10170

Receiver ID	Status	Sound Pressure Levels (dBA)				Relative Height (m)	Coordinates (UTM NAD 83 Z19N)			Distance to Nearest Turbine (m)	Distance to Nearest Turbine (ft)
		Gamesa G90		GE 2.75 103 and 100							
		Unmit	Mit	Unmit	Mit		X (m)	Y (m)	Z (m)		
35	Non-participating	31	31	32	32	4	393487	4927093	133	3092	10146
36	Non-participating	32	32	32	32	4	393503	4927139	136	3050	10006
37	Non-participating	32	32	32	32	4	393496	4927162	137	3041	9977
38	Non-participating	32	32	32	32	4	393446	4927149	138	3088	10131
39	Non-participating	32	32	33	32	4	393442	4927173	139	3076	10091
40	Non-participating	32	32	33	32	4	393432	4927191	139	3072	10080
41	Non-participating	32	32	33	32	4	393421	4927210	140	3069	10069
42	Non-participating	32	32	33	32	4	393411	4927239	141	3060	10038
43	Non-participating	32	32	33	33	4	393464	4927244	139	3015	9893
44	Non-participating	32	32	33	33	4	393479	4927218	139	3019	9905
45	Non-participating	33	33	33	33	4	393615	4927374	139	2817	9242
46	Non-participating	33	33	33	33	4	393630	4927281	137	2862	9390
47	Non-participating	33	33	33	33	4	393618	4927302	138	2859	9379
48	Non-participating	33	33	34	33	4	393376	4929110	159	2481	8139
49	Non-participating	27	27	27	27	4	395060	4932606	309	2584	8476
50	Non-participating	33	33	34	33	4	394198	4927414	131	2355	7726
51	Non-participating	33	33	34	33	4	394320	4927308	134	2349	7708
52	Non-participating	32	32	33	33	4	394490	4927171	134	2353	7718
53	Non-participating	33	33	33	33	4	394750	4927147	128	2235	7332
54	Non-participating	32	32	33	33	4	394693	4927051	126	2345	7694
55	Non-participating	33	33	34	33	4	394853	4927042	129	2279	7476
56	Non-participating	32	32	33	33	4	395044	4926729	126	2495	8184
57	Non-participating	32	32	33	33	4	395093	4926769	129	2441	8009
58	Non-participating	30	30	31	30	4	395172	4926499	127	2677	8784
59	Non-participating	33	33	33	33	4	397407	4926861	163	2467	8093
60	Non-participating	34	34	34	34	4	397324	4927102	192	2212	7257
2b	Buffer	43	43	43	43	1.5	396587	4928636	334	0	0
4b	Buffer	45	45	46	45	1.5	397112	4929664	280	0	0

APPENDIX B: TURBINE LOCATIONS

Figure B1: Turbine Locations

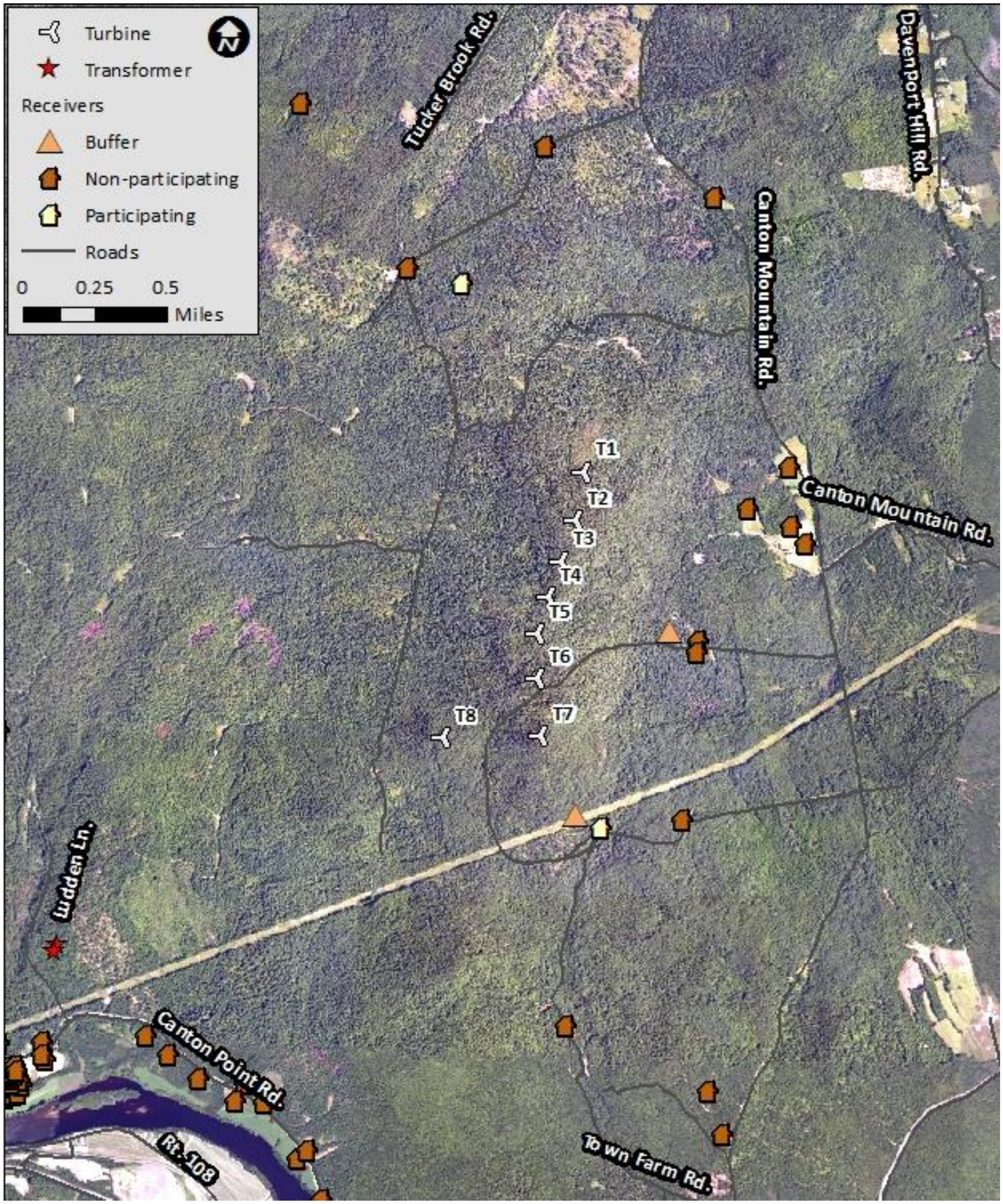


Table B1: Turbine Information

Turbine ID	Turbine Model	Modeled Sound Power (dBA)	Turbine Sound Power (dBA)	Hub Height (m)	Coordinates (UTM NAD83 Z19N) (at Hub Height)		
					X (m)	Y (m)	Z (m)
T1	GE 2.75-103	109	105	85	396625	4930556	540
T2	GE 2.75-103	109	105	85	396576	4930287	546
T3	GE 2.75-103	109	105	85	396500	4930057	550
T4	GE 2.75-103	109	105	85	396425	4929860	550
T5	GE 2.75-103	109	105	85	396364	4929651	539
T6	GE 2.75-103	109	105	85	396365	4929406	545
T7	GE 2.75-103	109	105	85	396382	4929083	555
T8	GE 2.75-100	110.5	106.5	85	395844	4929075	490
T1	Gamesa G90	109	105	78	396625	4930556	533
T2	Gamesa G90	109	105	78	396576	4930287	539
T3	Gamesa G90	109	105	78	396500	4930057	543
T4	Gamesa G90	109	105	78	396425	4929860	543
T5	Gamesa G90	109	105	78	396364	4929651	532
T6	Gamesa G90	109	105	78	396365	4929406	538
T7	Gamesa G90	109	105	78	396382	4929083	548
T8	Gamesa G90	109	105	78	395844	4929075	483

Table B2: Transformer Information

Source ID	Sound Power Level (dBA)	Relative Height (m)	Coordinates (UTM NAD83 Z19N)		
			X (m)	Y (m)	Z (m)
Canton Transformer	93	3	393699	4927916	168
Saddleback Transformer	93	3	393683	4927887	166

Table B3: Modeling Parameters

Parameter	Setting
Ground Absorption	Spectral for all sources, G=0.5
Atmospheric Absorption	Based on 10 Degrees Celsius, 70 % Relative Humidity
Reflections	None
Receiver Height	4 m for residences, 1.5 meters for grid and 500 ft buffers